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The Stability of Water Ejector Using in Heating System

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Abstract

In the heating system, the water ejector can use the "surplus pressure" to pump return water from return pipe instead of using mixing pumps, thus achieving the purpose of energy conservation. The water ejector is normally devised in the design condition, however, it usually does not operate at the design point because the pressure and flow rate of water in water ejector varies with the fluctuation of adjacent heat consumer, which causes the deviation of the indoor air temperature from the designed value. In the present study, the allowed pressure fluctuation of water ejector was investigated under the condition that the indoor air temperature was maintained in a certain range. The experimental results showed that when indoor air temperature was set at 18^{+2}_{-1} °C, the allowed pressure fluctuation range for the water ejector in Harbin was -10%～20%, and it expanded as the outdoor design temperature increased and/or the supply water temperature of primary network reduced.

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1. Introduction

An ejector is a pump-like device that converts the pressure energy of fluid flow to kinetic energy and creates a low pressure zone which draws in and entrains a suction fluid. After passing through the throat of the ejector, the mixed fluid expands and the velocity reduces, resulting in converting kinetic energy back into pressure energy. The ejector

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is more advantageous than conventional pumps in terms of some characteristics including no moving parts, no external power required, low maintenance cost, simple compact and easy to install.

The working principles of the ejector were originally found in sixteen century. The basic design theories of ejector were founded in 1860s by Zeumen according to the law of conservation of momentum, then those theories were developed and improved by Zeumen and Runkin, however, their theories failed to solve some problems with respect to the design of the ejector, such as the proper section form and the axial dimension of the ejector. In 1940s, Keenan studied theoretically and experimentally the characteristics of an ejector without the diffusion chamber, with air used as the working fluid. The results showed that the performance curves deduced by theoretical analysis agreed well with those obtained by experiments [1]. Then those theories were improved by themselves and two practical calculation methods were proposed, namely constant-pressure mixing theory and constant-area mixing theory [2]. In 1977, Munday and Bagster proposed a new theory of ejector with particular reference to steam jet refrigerator performance, which was based on the assumption that two discrete streams-the motive stream and the evaporated vapor-maintaining their identity down the converging duct of the diffuser. In that case, it was postulated that the secondary vapors reach sonic velocity and are therefore effectively chocked at some cross section of the ejector. Results indicated that steam jet refrigeration units should be designed for the most often prevailing conditions, rather than the most severe, to achieve greater overall efficiency [3]. Those aforementioned studies had greatly promoted the application of the ejector, and nowadays they are applied in many areas, such as the ejector of the thermal management system for aerospace application by Sherif [4], the vapor ejector for the hydraulic discharging system designed by Spiridonow [5], the ejector for pneumatic transmission by Ding [6], the ejector refrigeration system of solar energy by Wang [7], and the water ejector for waste heat recovery by Zhao [8].

The application of ejector in centralized heating system had also drawn some attention, such as the application in the high and low regions direct connection system by Wang [9], in primary and secondary network direct connection system by Yan [10] and in the heating system by Ren [11]. Although a vast majority of researches were conducted on the application of ejector in centralized heating system, most of them emphasized the design of the ejector in specific engineering, but surprisingly, ignored the stability of the ejector in the actual operation. In the present study, the factors which may influence the stability of the ejector in secondary side mixed-water system were discussed, and the stability of the ejector was studied. This study is expected to provide some practical control and operation strategy for the application of ejector in secondary side mixed-water system.

2. Working principle of the water ejector

The working fluid got accelerated in jet nozzle at a static pressure of P0. In the end of the jet nozzle, it had the maximum velocity and the lowest static pressure which was even lower than the suction fluid thus causing mixing. And concurrently, the suction fluid was drawn into the water ejector at a static pressure of Ph. With the increase of the distance from the nozzle, the mass flow of the mixed fluid grew. In the entrance section of the mixing chamber, the velocity of the fluid increased and its static pressure reduced. Inside the mixing chamber, as the fluid flowed away from the jet nozzle, the pressures of the working fluid and suction fluid were tending towards uniformly and had a small increase, and the significant characteristic of this process was a strong exchange of momentum, kinetic energy, and heat energy between working fluid and suction fluid. In the diffusion chamber, the pressure of the mixed fluid continued to increase, and the kinetic energy of the mixed fluid was transferred to potential energy of pressure. In the end of the water ejector, the mixed fluid got its discharge pressure Pg.

3. Numerical model

In this study, the water ejector was used in secondary side mixed-water system. In general, the water ejector was designed and chosen at the design point, but it operated at off-design condition most of the time. When the working condition of water ejector deviated from the design point, the flow rate and temperature of the water flowing through the water ejector would change, thus influencing the indoor air temperature. To ensure a good indoor thermal comfort, the water ejector was supposed to have a relatively stable working condition, however, the pressure difference between the entrance of the working fluid and the discharged mixed fluid was the main factor that influenced the stability of a given water ejector.

According to the principle of mass conservation, and the definition of the jet coefficient u and the Bernoulli's equation:

$$G_g = (1+u)G_0 = (1+u)\varphi_1 f_p\sqrt{\frac{2\Delta P_p}{\upsilon_p}} \tag{1}$$

Comparing the parameter in general cases to the parameter under the design condition:

$$\overline{Q} = \frac{t_n - t_w}{t_n' - t_w'} = \left(\frac{t_g + t_h - 2t_n}{t_g' + t_h' - 2t_n'}\right)^{1+b} = \overline{G}\frac{t_g - t_h}{t_g' - t_h'} \tag{2}$$

Where $\overline{Q}$——the relative load ratio, $\overline{Q} = \frac{Q_1}{Q_1'} = \frac{Q_2}{Q_2'} = \frac{Q_3}{Q_3'}$;

$\overline{G}$——the relative circulating water flow ratio, $\overline{G} = \frac{G}{G'}$;

For those directly connected systems using water ejector, the water mixing ratio u would keep invariant if the flow resistance coefficients of the pipeline after the outlet of the water ejector remained unchanged:

$$u = u' = \frac{\tau_g - t_g}{t_g - t_h} = \frac{\tau_g' - t_g'}{t_g' - t_h'} \tag{3}$$

Eq. (2) can be simplified to the following equations:

$$t_n = \overline{G}\frac{t_n' - t_w'}{t_1' - t_2'}(t_1 - t_2) + t_w' \tag{4}$$

$$t_n = \frac{t_1 + t_2}{2} - \frac{t_1' + t_2' - 2t_n'}{2}\left(\overline{G}\frac{t_1 - t_2}{t_1' - t_2'}\right)^{\frac{1}{1+b}} \tag{5}$$

The Eqs. (2) and (3) in this case were also solved by the MATLAB programming using the Eqs. (4) and (5) as the control function, and then the inlet and outlet temperature of each house not only in single pipe system but also in double pipe system can be decided.

4. Results and analysis

4.1 The relationship between $\overline{G}$ and t_n

4.1.1 The influence of system form on the relationship between $\overline{G}$ and t_n

For a double pipe system in Harbin, assuming that the supply water temperature of the secondary network, the mixed water temperature at the outlet of ejector and discharge water temperature of the user (abbreviated as supply/mixed/discharge water temperatures in the following) were 95.0°C, 85.0°C, and 65.0°C respectively, the design outdoor air temperature was -26.0°C and the design indoor air temperature was 18.0°C, then the relationship between $\overline{G}$and t_n was shown in Fig .1

When the relative circulating water flow ratio was 1.0, namely the system running under the design condition, the indoor air temperature was 18.0°C. While it was less than 1.0, it meant that the actual flow rate was less than the design flow rate, and if the supply water temperature of the secondary network and the discharge temperature of the user side remained unchanged, then the heat released by the water would be less than the design heating load of the user, therefore the indoor air temperature was lower than 18.0°C. On the other hand, as the relative circulating water flow ratio was larger than 1.0, it meant that the actual flow rate exceededthe design flow rate, then the corresponding indoor air temperature was supposed to be higher than 18.0°C. According to the Code for construction and acceptance of heating and sanitary, the allowed deviation temperature range of indoor air temperature was -1.0°C to +2.0°C, then it was indicated that the allowed relative circulating water flow ratio was 0.90~1.26.

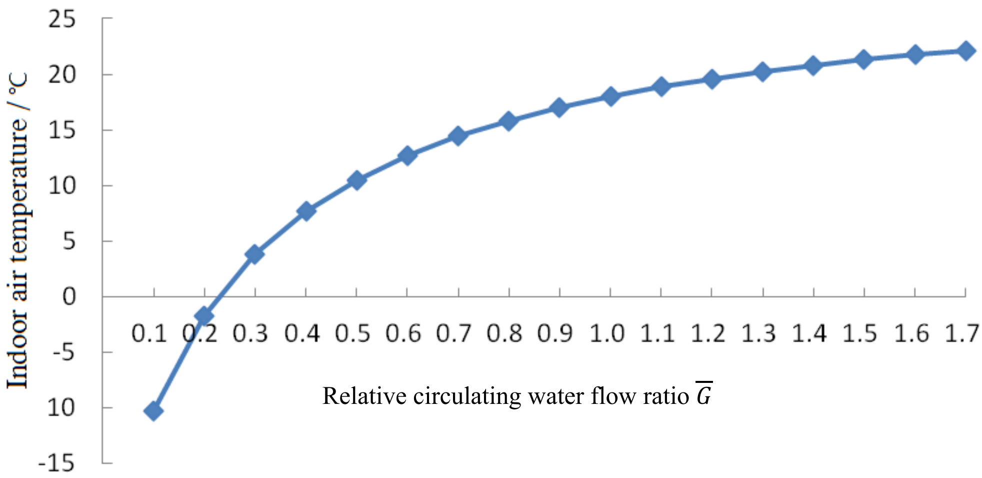

Fig .1 the relationship between $\overline{G}$ and indoor air temperature in double pipe system

For a single pipe system in Harbin, if the supply water temperature of the secondary network and the mixed water temperature at the outlet of ejector and discharge water temperature of the user were 95.0°C, 85.0°C, 65.0°C respectively, the design outdoor air temperature was -26.0°C, the design indoor air temperature was 18.0°C, the relationship between $\overline{G}$and $t_n$were shown in Fig .2

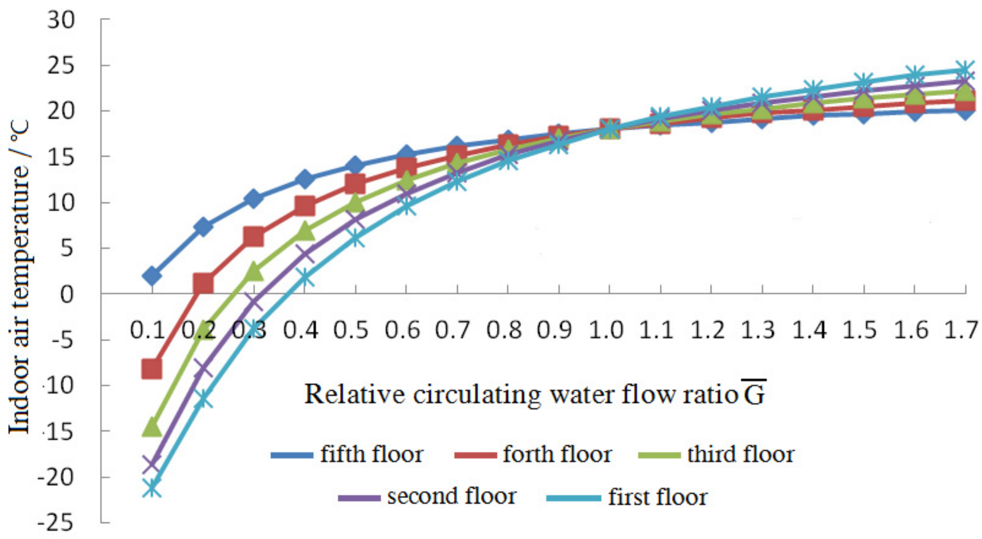

Fig .2 the relationships between $\overline{G}$and indoor air temperature in single pipe system

There were some analogies between the single pipe system and double pipe system. According to the relevant code, the allowed range of relative circulating water flow ratio was 0.93~1.16, which was small than that in the double pipe system.

4.2 The relationship between $\overline{G}$ and ΔP_p

When the water ejector was applied in a secondary side mixed-water system, the water mixing ratio would remain unchangeable if the resistance coefficients of the user side were invariant, then the flow of the water ejector and user side would change by the same proportion. Using the methods introduced in part three, we can determine in certain system form, design outside temperature, the design supply/mixing/discharge water temperatures, the number of the floors and the heat transfer coefficient all those efforts, the allowed water flow ratios in water ejector at different conditions are shown in Tab.1. the water flow of the water ejector was proportional to the square root of the pressure drop in water ejector, namely $G_g \propto \sqrt{\Delta P_p}$, thus $\Delta P_p \propto {G_g}^2$, the allowed pressure variation ranges are also shown in right of the Tab.1.

Tab.1 the allowed water flow ratios in water ejector at different conditions

Cities	System form	Supply/mixing/return water temperature °C	The allowed pressure drop ratios		The allowed water flow ratios	
			-1°C	+2°C	-1°C	+2°C
Harbin	Double pipe	95/85/60	0.808	1.598	0.899	1.264
		110/85/60	0.863	1.362	0.929	1.167
		130/95/70	0.874	1.318	0.935	1.148
		150/95/70	0.897	1.245	0.947	1.116
	Single pipe of five floors	95/85/60	0.882	1.341	0.939	1.158
		110/85/60	0.895	1.232	0.946	1.110

	Single pipe of ten floors	95/85/60	0.884	1.318	0.940	1.148
		110/85/60	0.897	1.223	0.947	1.106
Changchun	Double pipe	95/85/60	0.801	1.633	0.895	1.278
		110/85/60	0.857	1.381	0.926	1.175
		130/95/70	0.869	1.336	0.932	1.156
		150/95/70	0.893	1.259	0.945	1.122
Shenyang	Double pipe	95/85/60	0.790	1.687	0.889	1.299
		110/85/60	0.848	1.414	0.921	1.189
		130/95/70	0.859	1.367	0.927	1.169
		150/95/70	0.884	1.281	0.940	1.132
Xining	Double pipe	95/85/60	0.767	1.809	0.876	1.345
		110/85/60	0.830	1.479	0.911	1.216
		130/95/70	0.841	1.428	0.917	1.195
		150/95/70	0.869	1.329	0.932	1.153
Beijing	Double pipe	95/85/60	0.748	1.924	0.865	1.387
		110/85/60	0.812	1.543	0.901	1.242
		130/95/70	0.826	1.486	0.909	1.219
		150/95/70	0.854	1.374	0.924	1.172
Zhengzhou	Double pipe	95/85/60	0.723	2.097	0.850	1.118
		110/85/60	0.790	1.633	0.889	1.278
		130/95/70	0.805	1.568	0.897	1.252
		150/95/70	0.835	1.435	0.914	1.198

5. Conclusion

In the present study, relevant formulas were established to calculate the stability of the water ejector, and some factors that might influence the stability of the water ejector, such as the system form, the design outdoor air temperature, the design supply/mixing/discharge water temperatures, the number of the floors and the heat transfer coefficient were analyzed. Then, the allowed water flow ratios at different conditions were given. At last, according to the properties of the water ejector, the relationships between the allowed water flow ratios of user side and of water ejector, the relationships between the allowed water flow ratios of water ejector and the allowed pressure drop ratios, and the allowed pressure drop ratios at different conditions were given.

The main conclusions were as follows:

1) In the same city, the single pipe system had a larger range of allowed pressure drop ratios than the double pipe system, and this range decreased with the growth of the number of the floors.
2) When the indoor air temperature was set at 18^{+2}_{-1} °C, the allowed pressure drop ratios for Harbin, with the lowest design outdoor air temperature, was 0.897~1.293, namely the allowed pressure drop fluctuation range from the design condition was -10%~+23%. And this range would increase with the rise of the design outdoor air temperature.
3) The design supply and return water temperatures also influenced the stability of the water ejector, when the design water temperature difference between the supply and return water temperatures increased, the allowed pressure drop fluctuation range reduced as a result.
4) The heat transfer coefficient of the radiator was not the main factor that influenced the stability of the water ejector, and the allowed pressure drop fluctuation range reduced with the growth of the heat transfer coefficient.

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